Local scale EM geophysical survey to estimate hydrogeological parameters related to environmental problems

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Abstract

Hydrogeologists need to know the heterogeneous distribution of hydraulic conductivity in the field to protect aquifers against contamination. This parameter can be obtained with direct methods, with drillings and pumping tests, but indirect methods, surface geophysical survey can help to locate a limited numbers of boreholes and put them on the right places. The Radiomagnetotelluric (RMT) geophysical method was developed at CHYN (University of Neuchatel) in the last years to investigate the most permeable areas in loose sediments and fractured rocks. Two men crew can achieve hundreds of vertical frequency soundings a day, map hidden geological structures and obtain indirect estimation of hydraulic conductivity. Hungarian examples are presented.

Introduction

In the most cases contamination are happened in a small scale, like leakage in landfills and hydrogeologists can only predict the consequences of this contamination if they know the heterogeneous distribution of the field of hydraulic conductivities. This parameter

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determines the flow velocity and contaminant transport according to Darcy's Law.

With direct methods, drillings and pumping tests, it is possible to obtain the permeability of aquifer, to prepare potentiometric surface maps and understand the flow field in the aquifer. However direct methods are time consuming and expensive. Surface geophysical survey, an indirect method, can help to get a good conception about the geological structures and about hydraulic conductivities. There exist several geophysical methods for underground investigation, but for local scale survey a new electromagnetic method was developed and experimented: the Radiomagnetotellurics. This method is a fast and reliable method to obtain information in a very local scale and help to delimit with sharp contours the contact of geological boundaries, locate buried river channels and find the most fractured zones in hard rocks.

Basic principles about Radiomagnetotellurics

Since the 1980s, the Centre of Hydrogeology at the University of Neuchatel (CHYN) has concentrated on the application and development of electromagnetic methods and equipment. These methods appeared to have the potential of being appropriate for investigating heterogeneous carbonate rocks and structures in loose sediments. Instead of measuring a medium galvanic resistivity as a result of an electric current injected into the ground (geoelectrics), EM methods measure electric and magnetic fields of the ground, that are created by induction from external, natural or artificial EM fields.

The Very Low Frequency (VLF method) was mainly developed for mineral exploration (Paal 1965). It uses radio-signals emitted by terrestrial transmitters distributed all around the world in the frequency range from 3 to 30 kHz. The VLF method measures the earth's electromagnetic (EM) response induced by the EM fields emitted from these transmitters. The VLF-Resistivity (VLF-R) method measures the relation between the horizontal magnetic field with an induction coil and the electric field using two electrodes placed in the ground. This method determines apparent resistivities at the penetration depth of the used transmitter-frequency. For further theoretical details, the reader is referred to (Bosch & Müller 2005).

In mineral prospecting, the requirements on the sensitivity and resolution of VLF devices are not very high because the observed anomalies are very strong and the investigated targets are large. However, the principles of this method provided the possibility of rapid data acquisition and survey at a local scale. Consequently, electromagnetic methods have been adapted for engineering and environmental surveys and applied to hydrogeological investigations (Palacky et al. 1981; Meyer de Stadelhofen 1991; McNeill 1994).

Since electromagnetic methods appeared to have the potential to fulfil the needed requirements for karst research, an initial approach was done by the construction of a Very Low Frequency-Resistivity (VLF-R) prototype equipment (Müller 1982a; Müller 1982b), that works in the 12 – 24 kHz frequency-range. A magnetic induction coil with a diameter of 40 cm was used to measure the local horizontal magnetic field component H_Y. With a pair of Al-electrodes placed into the ground the horizontal, secondary electric field component E_X is measured. The signal-to-noise-ratio of the measured values is inversely proportional to the electrode spacing. An electrode spacing of 5 m was ascertained as a sufficient compromise between resolution and signal quality. For one polarization direction, this equipment provided from the measured values both apparent resisitivity ρ_a in Ωm and phase-shift Ψ in degree between the horizontal, magnetic and electric field component depending on the transmitter frequency. These two parameters allowed data interpretation based on magnetotellurics (MT) to calculate specific resistivity-depth-distribution (Fischer et al. 1981). With different frequencies and a fixed electrode spacing of 5 m VLF-R resistivity soundings are carried out several orders of magnitude faster, than with traditional geoelectric soundings using electrode-spacing variation. Moreover, to the increased measurement speed, the VLF-R significantly enhanced the horizontal resolution for vertical structures as fractures and faults. The vertical resolution of VLF-R was limited due to the small frequency range. Investigation depths for the frequency-range used and the typical electric resistivities of karstified and massive limestones of the Swiss Jura Mountains (100 to 3000 Ωm) vary between 40 m and 200 m. Consequently, the VLF-R method could detect major faults and fractures, but could not separate horizontal layers at very shallow depths. However, the presence of electrically conductive overburden (some tenth of Ωm) reduces the investigation depth, it remained to excessive for very shallow depths investigation. A device extended to the Low Frequency range (LF) was subsequently constructed. This device works at between 12 and 240 kHz and was called RMT. The penetration depths of the RMT device, varies between 10 to 200 m in karstified and massive limestone. In sedimentary environments, with their significantly lower electric resistivities, the RMT also provides detailed information in the first 30-50 m depth. The apparatus has been successfully applied to a variety of environmental, engineering and academic investigations in karstified, fissured and porous media. Compared to geoelectrics, RMT significantly increased the speed for carrying out resistivity soundings. Two persons can perform at least 150 soundings per day. Thus, the method offers the possibility of covering large areas (Fig 1).

According to the calculated true resistivity we propose an approximation, which correlate resistivities and hydraulic conductivity. This correlation is obtained from about 70 pumping test on different geological settings in loose sediments (Fig. 2).

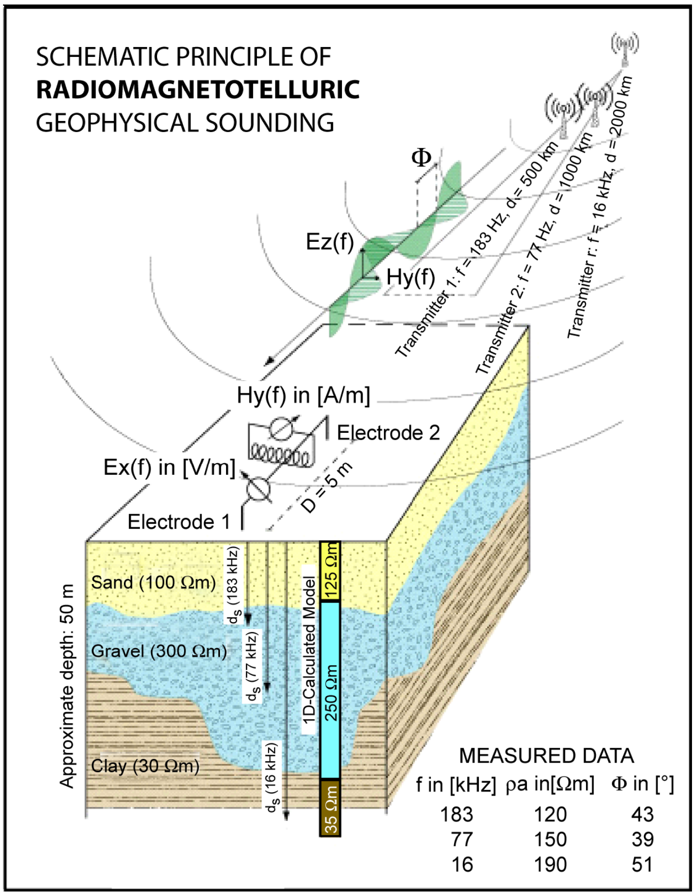

Fig. 1. Schematic principle of RMT sounding. $d_S(f)$ indicates the penetration depth of the transmitter-frequency (f)

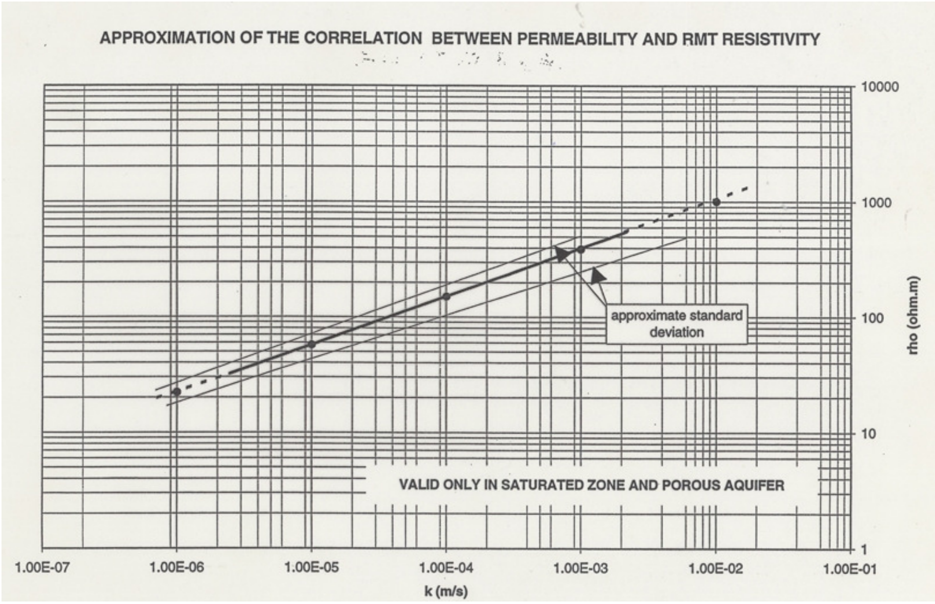

Fig. 2: Approximation of hydraulic conductivity obtained with RMT resistivities. Correlation is valid only with electrical conductivity of the water between 500-800 µS/cm at 25 °C.

Hungarian case studies

The investigated spring gallery of Pálihálápuszta (Transdanubian Central Range, Bakony Mts.) is situated in a binary karst basin. The karst part of the catchment is built up of Mid-Cretaceous Limestone, the non-karst part consists of Pleistocene Loess. The bedrock of both aquifers is a Mid-Cretaceous Clay-Marl.

Vulnerability of the spring gallery was assessed by using the European Approach in the frames of a methodological study related to COST-620. Due to the lack of sufficiently detailed geological and hydrogeological data, the reliability of this first assessment was rather poor the behaviour of the non-karst part of the reservoir and its contribution to the vulnerability was impossible to predict. The most obvious solution was to improve the reliability of the hydrogeological scenario with help of new data acquisition.

Several hundreds fast EM soundings (RMT) gave information about the areal extent of the catchment and the hydrostratigraphy (Ferenczi, 2003; Petró 2003). As a result of these investigations we had to modify the original "binary karst" model to a „porous and block-karst" model. Consequently a new conceptual model was developed which strongly influence the protection area of the catchment.

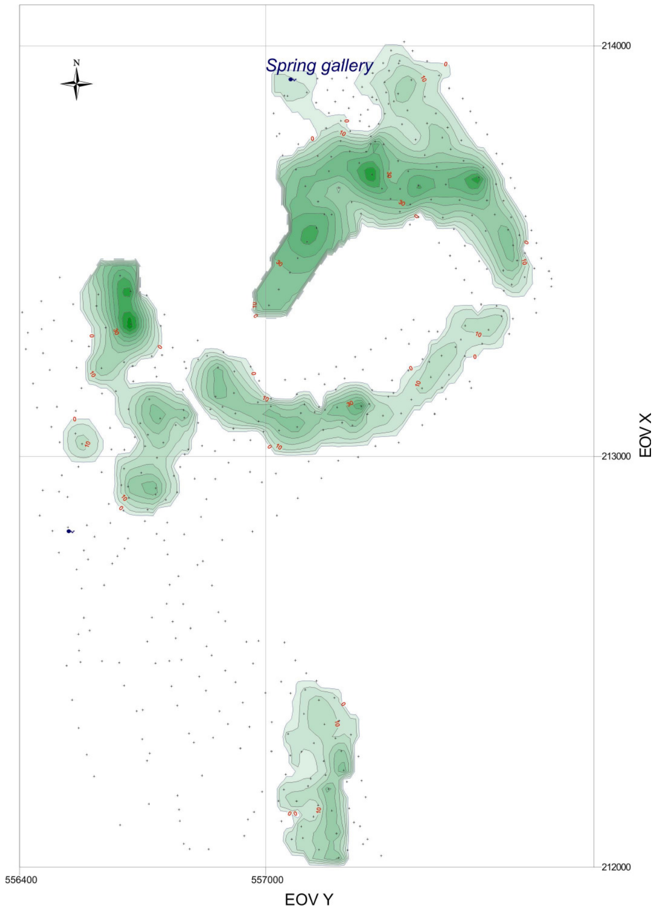

Fig. 3. Map of the hidden limestone reef bodies covered with several metres of aeolian Loess (Ferenczi, 2003)

The second test area is located at the Balaton Highland. In this area the RMT method allows to identify the most fractured zones in the field and estimate the direction and intensity of fracture development under several meters of aeolian overburden. The survey in the Paleozoic Sandstone show up a non fractured block (no phase difference between the multi-directional measurements) and a strong fractured block with a lineament (with large differences between the phase values) which allow us to locate the most permeable zone in the sandstone and plan a drillhole for water supply in the optimal place (Fig. 4).

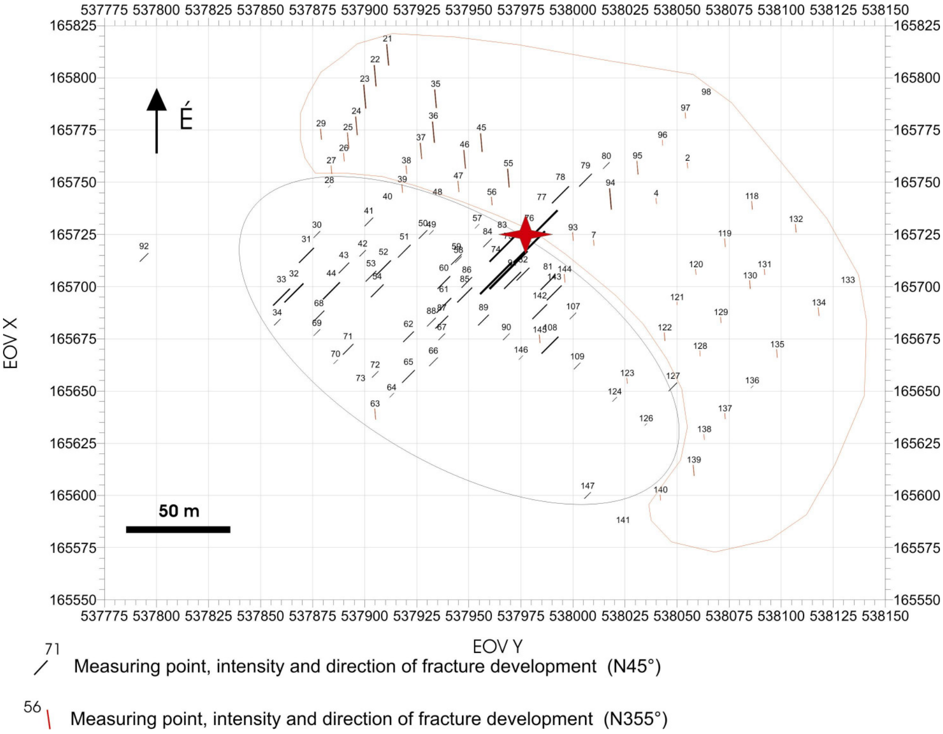

Fig. 4.: Proposed location for planned water well (red star) (after Csurgó, 2006)

Conclusion

The RMT seemed to be a fast and reliable tool to help hydrogeologist to obtain important information on a very local scale about heterogeneous distribution of permeability.

References

Bosch, F.P. & Müller, I., 2005. Improved karst exploration by VLF EM - Gradient survey: comparison with other geophysical methods. Near Surface Geophysics, 2005, p.299-310.

Csurgó, G., 2006. Vízkutak kitűzése geofizikai módszerekkel a Dunántúli-középhegységben dolomite és homokkő anyagú vízadókban. Diplomamunka, ELTE TTK, Alkalmazott és Környezetföldtani Tanszék (Unpublished MSc-Thesis, in Hungarian)

Ferenczi, A., 2003. Elektromágneses (VLF/R) mérések a pálihálàspusztai forrásgaléria vízgyűjtőjén. Diplomamunka, ELTE TTK, Alkalmazott és Környezetföldtani Tanszék (Unpublished MSc-Thesis, in Hungarian)

Fischer, G., Schnegg, P.A., Peguiron, M. & Le Quang, B.V., 1981. An analytic onedimensional magnetotelluric inversion scheme. Geophysical Journal of the Royal Astronomical Society 67: 257-278.

McNeill, J.D., 1994. Use of electromagnetic methods for groundwater studies. in Geotechnical and Environmental Geophysics, edited by S.H. Ward, 1, Society of Exploration Geophysics, Tulsa, Band 1: 191-218, dritte Ausgabe.

Meyer de Stadelhofen, C., 1991. Applications de la géophysique aux recherches d' eau. Lavoisier, Paris.

Müller, I., 1982a. Premières prospections électromagnétiques VLF (very low frequency) dans le karst en Suisse. Proceed. of the 7e congrès national de spéléologie, Schwyz: 173-181.

Müller, I., 1982b. Role de la prospection électromagnétique VLF (Very Low Frequency) pour la mise en valeur et la prospection des aquifères calcaires. Annales Scintifiques de l' Université de Besancon **1**: 219-226.

Paal, G., 1965. Ore prospecting based on VLF-radio signals. Geoexploration 3: 139-147.

Palacky, G.J., Ritsema, I.L. & Jong, S.J.D., 1981. Electromagnetic prospecting for groundwater in precambrian terrains in the Republic of Upper Volta. Geophysical Prospecting 29: 932-955.

Petró, I., 2003. A pálihálási vízbázis vízgyűjtő területének háromdimenziós hidrogeológiai jellemzője. Diplomamunka, ELTE TTK, Alkalmazott és Környezetföldtani Tanszék (Unpublished MSc-Thesis, in Hungarian)